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AD847504

RADC-TR-68-430
3 September 1968



SECOND SOURCE FOR CROSSED-FIELD AMPLIFIER

Peter Laurendeau
Richard Handy

Contractor: Raytheon Company
Contract Number: F30602-68-C-0291
Effective Date of Contract: 8 March 1968
Contract Expiration Date: April 1969
Amount of Contract: \$122,000
Program Code Number: 7E30

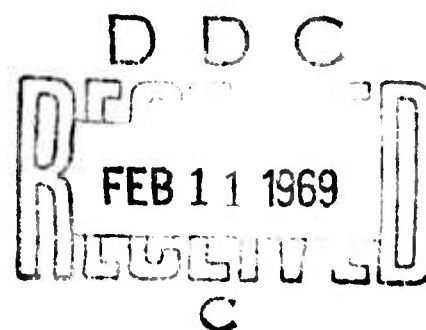
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**Peter Laurendeau
Richard Handy
Raytheon Company**

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FOREWORD


This Interim Report, covering the period 28 February to 28 June, 1968, is submitted by the Microwave and Power Tube Division of Raytheon Company, Waltham, Massachusetts. Overall project responsibility is borne by the Crossed-Field Amplifier Group, John F. Skowron, Manager. The mechanical and electrical design of the experimental models is performed by Peter Laurendeau, Senior Engineer, under the direction of Richard A. Handy, Engineering Section Manager.

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by D. T. Bussey, Rome Air Development Center (EMATE), Griffiss Air Force Base, New York, under Contract F30602-68-C-0291.

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This Technical Report has been reviewed and is approved.

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ABSTRACT

The main objective of this program is to develop a self-modulated forward-wave crossed-field amplifier at C-band with higher peak and average power capability than has been realized in the past. Tube performance objectives are 2 mW peak, 20 kW average, 50 microseconds pulse duration in C-band with 10% instantaneous bandwidth. During this report period, design approaches for a large, directly liquid-cooled anode circuit were examined, and development of the SSHL circuit was initiated. Sample vane assemblies for the initial operating model were successfully fabricated and preliminary cold test data were obtained.

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1.0 INTRODUCTION

This crossed-field amplifier development program is authorized by RADC contract No. F30602-68-C-0291. The new CFA will bear the Raytheon designation QKS1567. The prime objective of this program is to achieve CFA operation at a power output level of 2 MW peak power, 20 kW average power at 50 microseconds pulse duration. Such an amplifier will provide considerably higher performance capability than has been realized in the past. The tube is also to be developed to provide self-modulation, that is, full keying of the tube current on and off by the rf drive signal alone, with dc operating voltage continuously applied. The tube will be designed to operate at C-band over a 500 MHz band with 10 to 13 dB minimum gain at a single value of dc voltage.

Breadboard QKS1567 operating models will be built incorporating a version of the stub-supported helix line (SSHL) anode structure developed previously by Raytheon during an independent development project in 1967. Cold test studies were performed on the stub-supported meander line (SSML) and the stub-supported helix line (SSHL) during the first quarterly period. It was determined that the SSHL could more readily be designed for a significantly larger circuit height dimension (H_a) than the SSML and a decision was made to proceed with SSHL development for the QKS1567 anode.

Several secondary emitter materials have demonstrated the capability of providing the necessary peak current and of withstanding the back bombardment of the space charge. The QKS1567 cold cathode and bias electrode will be built according to the latest available information and techniques in order to provide adequate performance, stable operation, and long life.

2.0 INTERACTION SPACE DESIGN

2.1 Design Basis

The following crossed-field relationships (linear geometry) were used in the design calculations:

$$\text{Synchronous Voltage: } V_o = 238 \left[\frac{fp}{\theta} \right]^2 \text{ volts}$$

$$\text{Characteristic Current: } i_o = 4800 \times 10^{-6} \left[\frac{N^1 H_a f^3 p^4}{\theta^2 d^2} \right] \text{ amperes}$$

$$\text{Characteristic Magnetic Field: } B_o = 20.4 \left[\frac{fp}{\theta d} \right] \text{ Gauss}$$

where dimensions are GHz, inches, degrees and:

- p = circuit pitch
- θ = phase shift/circuit pitch
- d = anode-cathode spacing
- N' = number of active circuit pitches
- H_a = active circuit height.

The choice of operating voltage is a compromise between the relative ease of obtaining stable dc-bias self-modulation with low voltage, and the reduced cathode current demand gained through high voltage operation. An operating voltage (E_b) of 30 kV was considered reasonable, and a low E_b/V_o ratio of about 6 was chosen to facilitate stable operation of the bias electrode.

The number of active sections (N') was chosen as 65 to achieve a satisfactory balance between high anode dissipation area and the effects of circuit attenuation.

2.2 Design Parameters

The following table contains the design parameters and dimensions which have been established for the first QKS1567 tube model:

<u>Parameter</u>	<u>Symbol</u>	<u>Value</u>	<u>Units</u>
Center Frequency	F_o	5675	GHz
Synchronous Voltage	V_o	4970	volts
Characteristic Field	B_o	965	Gauss
Operating Voltage	E_b	31	kV
Operating Field	B	3500	gauss
Magnetic Field Ratio	B/B_o	3.63	---
Anode Interaction Diameter	D_A	2.400	in.
No. of Active Sections	N'	65	---
Anode Circuit Pitch	p	0.0966	in.
Anode Vane Diameter	D_v	0.070	in.
Diameter of Vane Coolant Passages	d_v	0.040	in.

3.0 ANODE CIRCUIT DEVELOPMENT

Work was undertaken to determine the advantages of a new high-dissipation slow wave circuit for the QKS1567 forward-wave crossed-field amplifier anode. The main goal was to develop a forward-wave circuit whose mechanical and electrical characteristics would be comparable to the SSML circuit used in the QKS1480* anode but with its active area and dissipation capability increased by a factor of 2, if possible. Initial development of this circuit, called the stub-supported helix line (SSHL), was completed during a Raytheon internal development project in 1967. The nature of the new circuit is described briefly below.

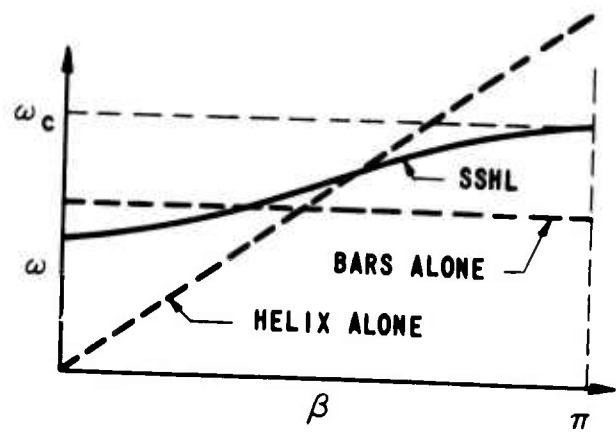
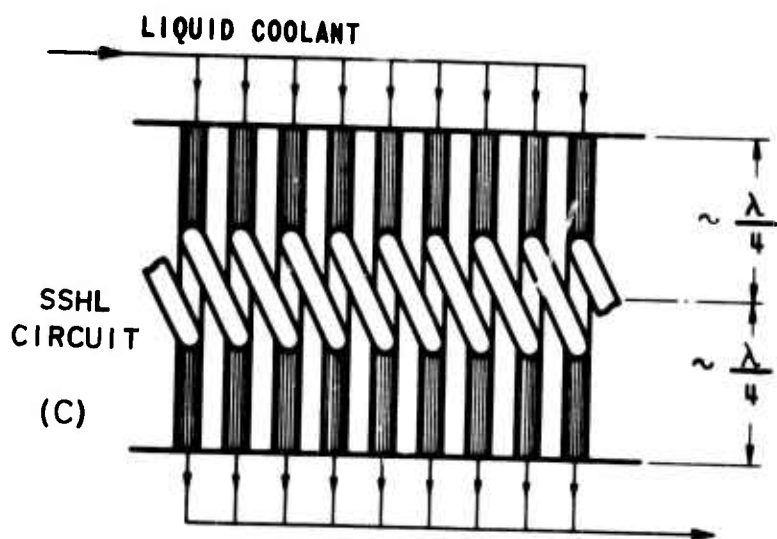
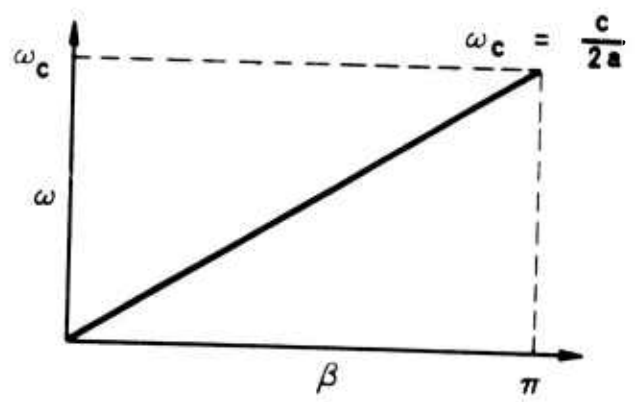
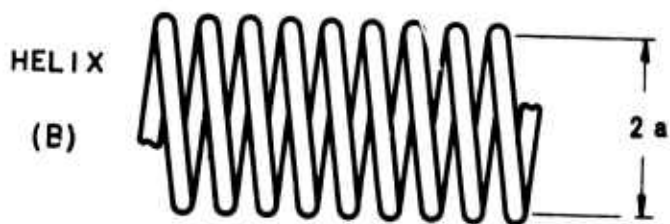
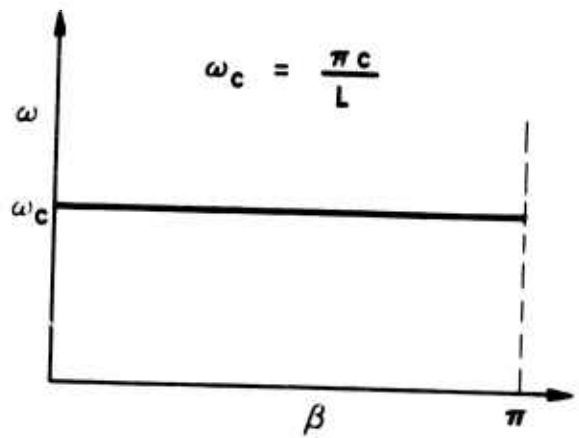
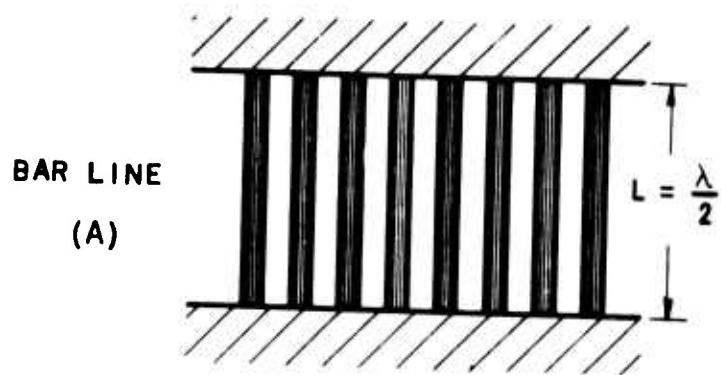
In Figure 3-1a, a simple, unloaded bar structure has almost no bandwidth; its very narrow frequency passband lies close to the frequency where the bars are a half-wavelength long. The bars can, of course, be made of hollow tubing, well-suited to direct liquid cooling and high thermal dissipation.

Figure 3-1b, shows a simple helix, like that used in traveling-wave tubes; it has an extremely wide passband, from dc to the frequency where the helix perimeter is a half wavelength. The helix is not normally capable of high power dissipation. In Figure 3-1c the bar circuit and the helix circuit are combined, resulting in a circuit which has both high thermal dissipation capability and the required cold passband of approximately half an octave for an operating band of 10%. The bars of the circuit support the helix approximately one-quarter wavelength above the ground plane and can be considered quarter-wave stubs - hence the name "stub-supported helix line."

The initial SSHL cold test models are shown in Figure 3-2. A liquid cooling scheme for the circuit, including coolant paths through the helix turns, is shown in Figure 3-3. This circuit approach may be required for the QKS1567 anode if the helix turn's cross-section is not adequate to carry away its rf losses. Another approach under study is the use of two helices instead of one to couple the bars, avoiding any need for direct liquid cooling of the helix turns and/or to increase the circuit bandwidth while maintaining maximum active circuit height (vane length).

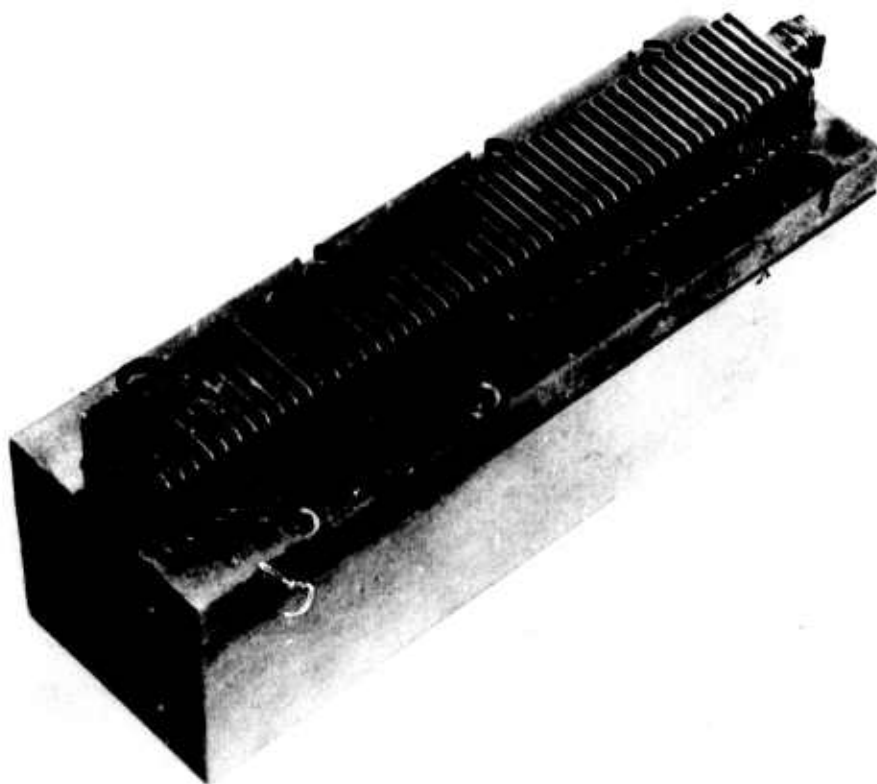
The dispersion of the parallel bar structure and the helix of Figure 3-2 were measured separately. The helix was then eutectic-brazed to the back of the strip-like bars of the stub-support structure. Figure 3-4 shows the dispersion of the helix, the stub-support structure, and the SSHL circuit formed by the tight coupling of the two together. The composite circuit has a dispersion curve of the desired shape and approximately correct slope for the QKS1567 anode. Circuit cold testing will be continued to establish the final anode circuit dimensions during the next quarter.

*MIT, Lincoln Laboratory, P.O. C-466 for C-Band CFA Feasibility Study.

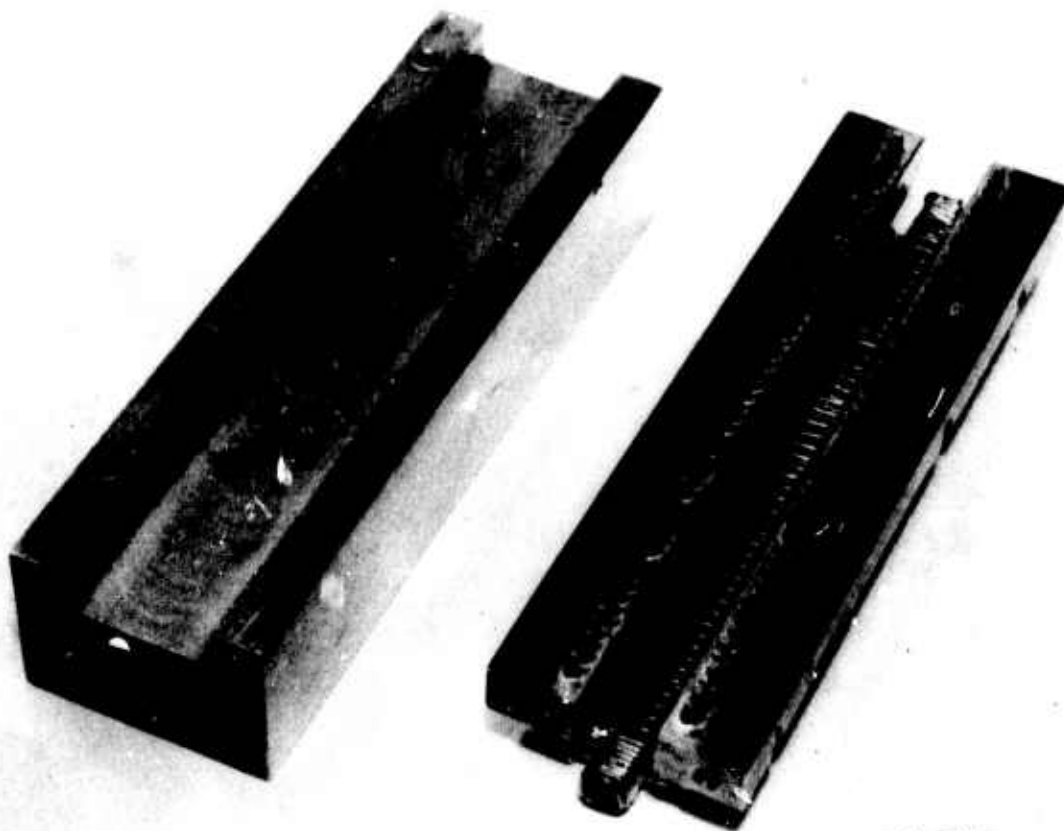


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Figure 3-1. Development of Stub-supported Helix Line (SSHL) Anode Circuit

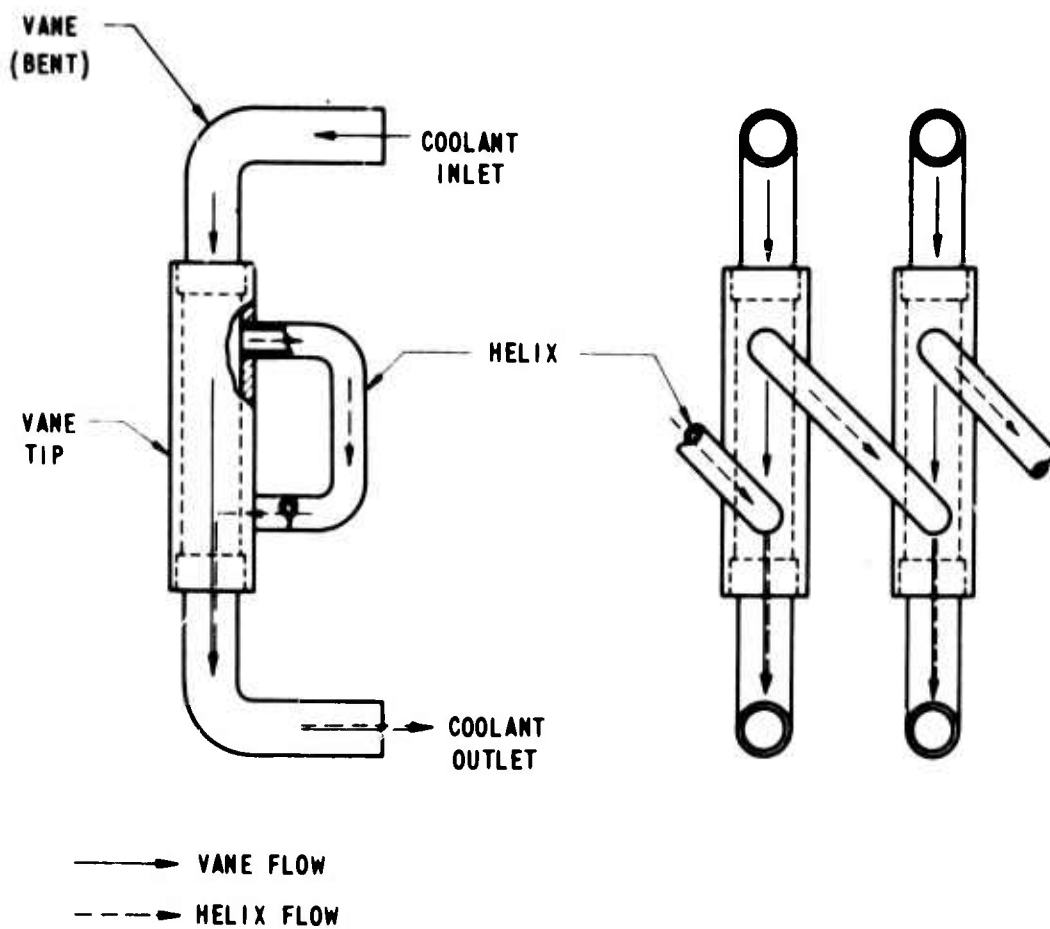


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Figure 3-2 Stub-Supported Rectangular Helix (SSHL No. 3)



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Figure 3-3 Vane and Helix Flow Paths for Directly Liquid-Cooled SSHL

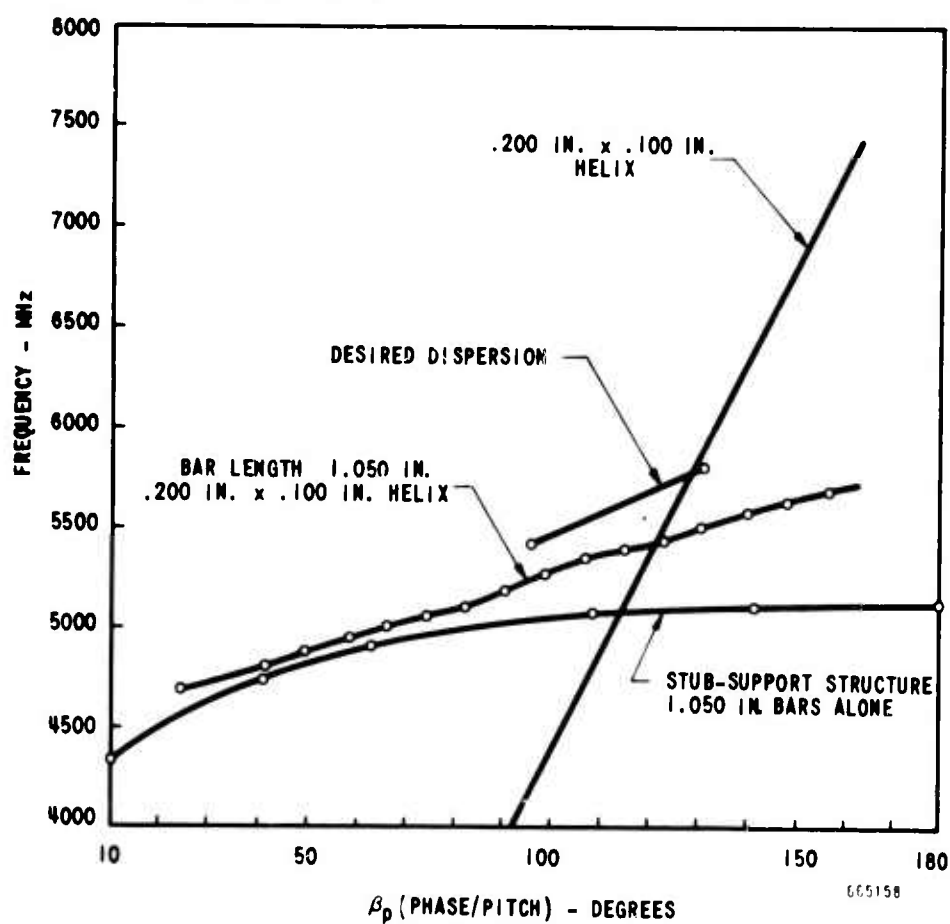


Figure 3-4 Frequency Dispersion - SSHL No. 2 (Stub-Supported Rectangular Helix)

An anode height of 0.800 in. or greater will be sought. A C-band backward-wave CFA employing 65 anode vanes of the same cross-sectional size and an active height of 0.800 in. has already demonstrated stable performance at 500 kW peak, 12 kW average without encountering a power limitation.

4.0 QKS1567 ANODE CONSTRUCTION AND COLD TESTING

The anode circuit will be fabricated from 0.070 in. OD x 0.040 in. ID OFHC copper tubing with molybdenum-copper vane tips and an interaction space vane pitch of 0.0966 inches. Rectangular helix turn sections will be mounted on the backs of the vanes. Liquid coolant will be carried directly to the molybdenum-copper vane tips with a tentative total metal thickness of 0.075 inches between coolant and electron impact surface. The water coolant flows from one coolant jacket to the other through all of the vanes in parallel. The input and output connecting ridge waveguides are short enough and have sufficient cross-sectional areas to obviate the need for direct water cooling.

Several sample anode vane subassemblies have been successfully brazed. Means were devised to permit the repeatable fabrication of accurate subassemblies required for good helix uniformity. The brazing of molybdenum vane tips to an all-copper vane subassembly created distortion problems which will be overcome by changes in the design of the parts. The use of a copper tube vane assembly will obviate the need to use deionized water for anode cooling, at least during test operation.

Cold test data using sample vane subassemblies soft-soldered into cylindrical support rings were taken to establish the adequacy of the dispersion curve, bandwidth, and interaction impedance. Dispersion and impedance plots are shown in Figure 4-1 and 4-2 respectively. With the particular dimensions selected, the SSHL cold circuit bandwidth is similar to that of the SSML (stub-supported meander line). Bandwidth is related to the slope of the ω - β curve or the frequency range covered for a given amount of circuit phase shift variation. Although the interaction impedance is lower by a factor of approximately 3 than that of a 0.400 in. high SSML anode, it is believed sufficient to provide operation with 10 to 13 dB gain over the required 10% bandwidth.

A plot of the impedance match of this cold test circuit to waveguide via an exponentially tapered-ridge waveguide transition section is shown in Figure 4-3. A reasonable preliminary impedance match was obtained from 4.5 GHz to 6.5 GHz, with the reflection coefficient less than 30%.

The rf input and output waveguide are in a straight line at right angles to the high voltage bushing. Alternate positioning of the rf input - output waveguide, making it parallel to the tube axis, would be possible without any major impedance re-matching work.

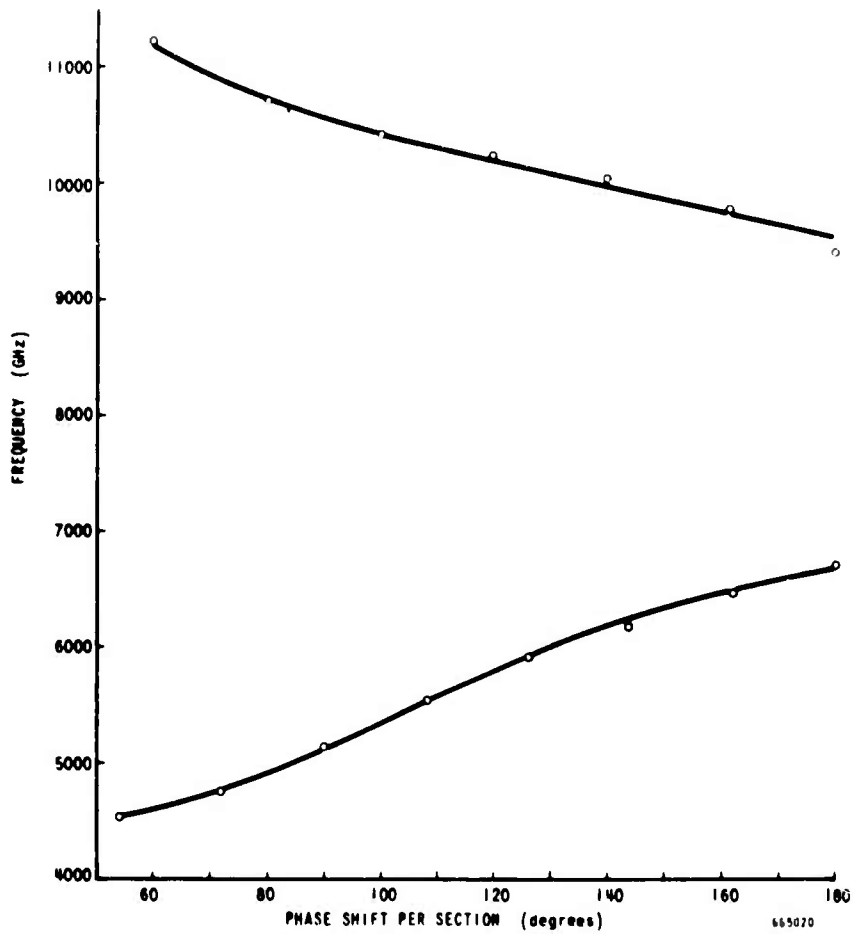


Figure 4-1 QK1567 Dispersion Curve - Cold Test Circuit

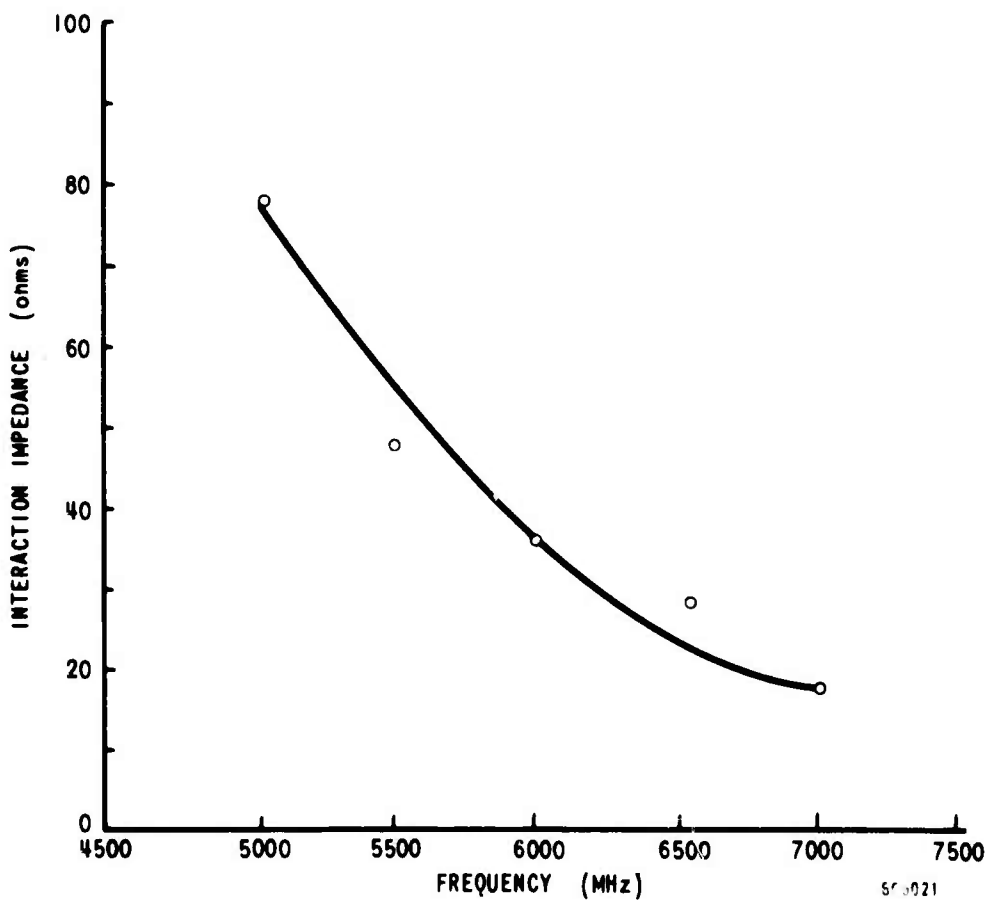


Figure 4-2 QK1567 Interaction Impedance - Cold Test Circuit

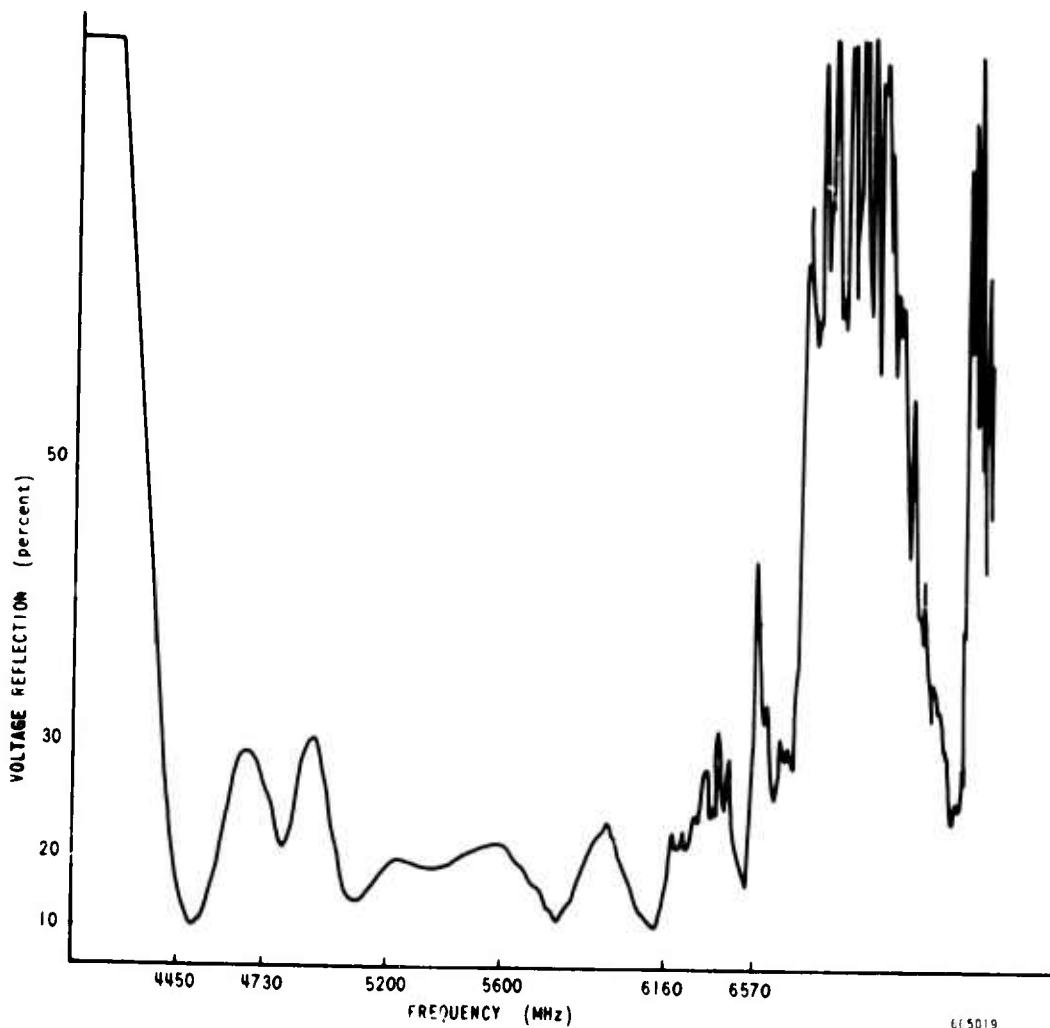


Figure 4-3 QK1567 Impedance Match - Cold Test Circuit

The resonances encountered on CFA hot test normally lie above the operating frequency range, usually near 180° phase shift (pi-mode). A second passband (backward-wave) is present in the SSL circuit. A stopband between the first and second passbands appears to provide sufficient separation to prevent interference from the upper pi-mode (Figure 4-1); the lower pi-mode is favorably situated to minimize lower voltage mode operation.

5.0 MAGNETIC CIRCUIT

A computerized check has been obtained of the magnetic field uniformity provided by the proposed pole piece geometry. Axial variations of 5.6% and 3.6% were computed for the anode and cathode surfaces respectively. Radial variations of 0.4% and 4% were computed for the anode and cathode respectively.

Actual magnetic field measurements will be performed shortly. Should any pole piece design modification be necessary, it is expected to be a minor one.

6.0 SUMMARY

The basic mechanical design of the entire tube has been established. Most parts have been detailed and all long-lead items have been ordered. Preliminary anode and cathode subassemblies have been started to aid resolution of major mechanical and electrical problems at an early date.

Cold test results on a sample cylindrical test anode have been encouraging to date. Continued impedance matching effort is expected to produce results yielding a voltage reflection coefficient of less than 20% from 4.5 GHz to 6.5 GHz.

7.0 PLANS FOR THE NEXT PERIOD

1. Complete design of initial cathode-bias electrode assemblies.
2. Continue construction of first hot test anode assembly.
3. Improve impedance match of anode-to-waveguide couplers.
4. Confirm magnetic field uniformity with flux measurements on a dummy pole assembly.

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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)

Raytheon Company
Microwave and Power Tube Division
Waltham, Mass. 02154

2a REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b GROUP

3 REPORT TITLE

SECOND SOURCE FOR CROSSED-FIELD AMPLIFIER QKS1567 C-BAND SELF-MODULATED FORWARD-WAVE AMPLIFIER

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

First Interim Report for period 28 February - 28 June 1968

5 AUTHOR(S) (Last name, first name, initial)

Peter Laurendeau
Richard Handy

6 REPORT DATE

3 September 1968

7a TOTAL NO. OF PAGES

10

7b NO. OF REFS

1

8a. CONTRACT OR GRANT NO.

F30602-68-C-0291

9a. ORIGINATOR'S REPORT NUMBER(S)

PT-1956

b. PROJECT NO.

Program Code No. 7E30

c.

ARPA Order No. 513

d.

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

RADC-TR-68-430

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12. SPONSORING MILITARY ACTIVITY

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13 ABSTRACT

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KEY WORDS

Crossed-field amplifier
 QKS1567
 C-Band
 Self-modulated forward-wave amplifier
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